Polarimetry with the elastic scattering in the CNI region at RHIC

I.G. Alekseev for RHIC SPIN Collaboration

ITEP, Moscow, Russia

RHIC is the first polarized proton collider in the world. Fast and precise measurement of the beams polarization is required for the success of its experimental program. This talk is devoted to the status and progress of RHIC polarimeters utilizing analyzing power of elastic scattering in the Coulomb-nuclear interference region.

PACS: 13.85.Dz, 13.88.+e and 29.27.Hj
Key words: polarization, elastic scattering, polarimeter, Coulomb-nuclear interference

1 Introduction

Elastic scattering in the region of very small momentum transfers is determined by two forces nuclear and electro-magnetic. Interference between these forces results in nonzero phase between amplitudes without spin flip and with single spin flip, which produces analyzing power A_N [1]. The first experimental test of this method was done at AGS in 1999 and turned out to be very successful [2]. The advantages of this process for the polarization measurement include:

– large cross section, which makes it easy to get large statistics;
– the fact that kinematics doesn't depend much on the beam momentum, which makes it easy to cover whole RHIC energy range from 25 to 250 GeV with a single setup;
– the fact that event is completely defined by recoiled particle, so we can measure only it and avoid difficulties of registration of the scattered proton, which is deflected too slightly to leave the beam;
– weak dependence of the analyzing power on the energy, which also helps us to cover RHIC energy range.

But there are also drawbacks, which include comparatively small (a few percents) analyzing power and the fact that it is not completely calculable theoretically. Due to the first drawback we need to collect large (about $2 \cdot 10^7$) statistics per one measurement. Due to the other we have to calibrate the polarimeter.

RHIC design stated a goal to measure beam polarization to 5% [3]. Fast measurements for beam adjustments are also required. In order to achieve these goals two polarimeters were built. One is a fast polarimeter with carbon target and the other is a polarimeter with polarized hydrogen jet target.

2 The proton-carbon polarimeter

The layout of the pC-polarimeter [4] is shown in fig. 1a. Its main parts are an extremely thin carbon ribbon target and six silicon strip detectors with 12 strips each. The strips are oriented along the beam. Even with the target being as thin as 5 ug/cm^2 with width 10 um the setup can produce up to 10^7 events per second at the maximum RHIC luminosity. Thus the most critical part of the setup is a very fast (dead-timeless) DAQ system.

Such a system was built based on the fast waveform digitizer [5] (WFD) modules recently developed at Yale University. Signals from silicon strip detectors are preamplified, transferred and shaped to obtain short (40 ns FW) pulses with the amplitude proportional to the charge, deposited in the detector. The pulse shapes are then digitized at the equivalent frequency of 420 MHz and analyzed inside the modules, providing the recoil carbon deposited energy and time of flight. The events are then filtered through lookup tables (LUT), checking the kinematic correspondence between the obtained values for carbon identification. The selected events are used to increment scalers and histograms in the modules, and stored in the on-board memory for off-line analysis. The main advantage of such an approach is that there is no data transfer to the host computer during a data taking run, which makes the system really dead-timeless.

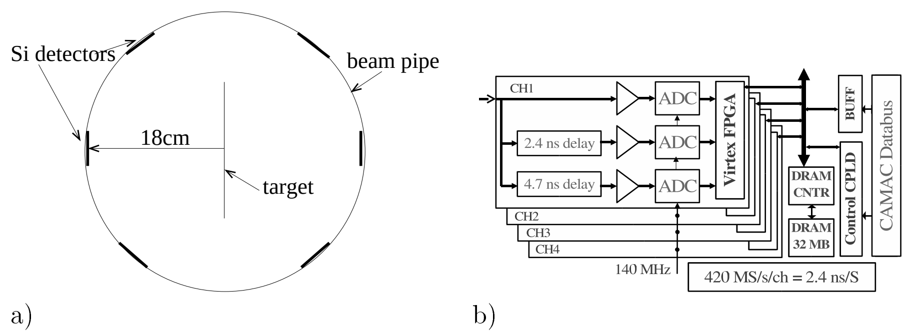


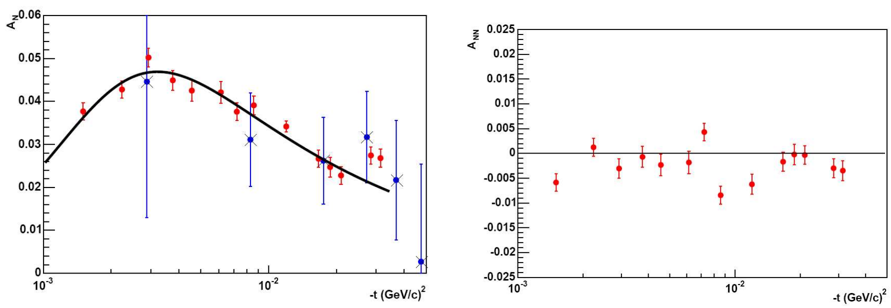
Fig. 1. a) pC-polarimeter layout (view along the beam). b) Block diagram of the WFD module.

The WFD is a CAMAC module hosting 4 independent channels (fig. 1b) with common storage SDRAM (64 Mbyte) and CAMAC control circuity. In each channel the input signal is split into three, two of which are delayed 1/3 and 2/3 of the ADC digitization period. Three 8-bit ADCs synchronously start conversions at 140 MHz resulting in triple equivalent digitization frequency. All the waveform analysis is done inside the Virtex-E Xilinx FPGA[6] chip at 70 MHz clock frequency. The analysis algorithm is rather specific since it has to process every 6 waveform points in parallel (the FPGA clock is only 1/6 of the digitization frequency).

Unfortunately analyzing power of the proton-carbon scattering is not exactly calculable — we have a very small knowledge about nuclear spin flip amplitude, which can change the analyzing power [1]. Another problem is that recoiled carbon nuclei has kinetic energy in the range below one MeV. When it hits silicon detector it first goes through a region called dead layer from which charge is not collected. Of course, this layer is made as thin as possible, nevertheless its contribution to the kinetic energy can't be neglected. Which in turn would provide significant uncertainty in the analyzing power. Thus pC-polarimeter being able to do relative measurement in a few minutes can't provide us with an absolute value of the polarization.

3 The proton-polarized hydrogen jet polarimeter

The other polarimeter consists of an extremely dense polarized beam of atomic hydrogen [7] and silicon strip detectors, measuring recoiled protons at angles close to 90° to the left and right of the RHIC beam [8]. Polarization of the target was measured with Breit-Rabi polarimeter and reversed each 10 minutes. The target polarization (including 3% dulution by molecular hydrogen) was 0.924 ± 0.018 with target density 10^{12} atoms/cm^2. The preliminary result of the measurement of single (a) and double (b) spin asymmetries in 2004 are presented in fig. 2. Only statistical errors are shown.



a) b)

Fig. 2. a) Single spin asymmetry of elastic proton-proton scattering at $P_{beam} = 100$ GeV/c from this work (dots) compared to E704 [9] data at $P_{\rm beam} = 200$ GeV/c (crosses). Theoretical curve correspond to no hadronic spin flip calculations scaled by factor 1.01. b) double spin asymmetry of elastic proton-proton scattering at $P_{beam} = 100$ GeV/c.

Raw left-right asymmetries for unpolarized beam and polarized target $\varepsilon_{\rm jet}$ and polarized beam and unpolarized target $\varepsilon_{\rm beam}$ for elastic scattering are connected by the equation:

$$R = \frac{P_{\rm jet}}{P_{\rm beam}} = -\frac{\varepsilon_{\rm jet}}{\varepsilon_{\rm beam}}, \qquad (1)$$

where $P_{\rm jet}$ and P_{beam} are the target and the beam polarizations and negative sign comes from the fact that for polarized beam - unpolarized target combination we detect recoil particle. Two weeks of running in 2005 provide about 4% statistical error in this ratio for one beam.

4 The road to 5% measurement

Let's run both polarimeters:

- pC-polarimeter each 1-2 hours during fills;
- pJet-polarimeter alternating beams each fill.

Then in a month of running we will know average polarization for each beam. We also will calibrate average analyzing power of pC-polarimeter. Then we can use pC-polarimeter to apply corrections for each experiment for its exact running time, which is of course different from H-Jet running time. Statistical error of pC-polarimeter for a month running is negligible and systematic error of pC-polarimeter is also small and can be estimated from the corrections applied to its analyzing power during the run 2005. These corrections (about 2% per week) came from the estimate of change in the dead layer due to the radiation aging of the silicon detectors. Thus the estimate for the systematic error introduced by pC-polarimeter is $1-2\%$. Total error in the polarization is:

$$(\frac{\Delta P}{P})^2 = (\frac{\Delta P_{\rm jet}}{P_{\rm jet}}[2\%])^2 + (\frac{\Delta R}{R}[4\%])^2 + (\frac{\Delta P_{pC}^{stat}}{P_{pC}^{stat}}[0\%])^2 + (\frac{\Delta P_{pC}^{sys}}{P_{pC}^{sys}}[2\%])^2 \approx 5\% \quad (2)$$

So RHIC polarimeters can provide both fast and precise beam polarization measurements required for RHIC success as a polarized proton collider.

References

[1] N. H. Buttimore *et al.*, Phys. Rev. **D59** (1999) 114010.

[2] J. Tojo *et al.*, Phys. Rev. Lett. **89** (2002) 052302.

[3] T. Roser et al., Polarized Proton Collider at RHIC, preliminary design report, 1997 (unpublished).

[4] O. Jinnouchi et al., Proceedings of the 16th International Spin Physics Symposium, Trieste, Italy, 2004, p. 515;
D.N. Svirida et al., Proceedings of the 16th International Spin Physics Symposium, Trieste, Italy, 2004, p. 722.

[5] S. Dhawan, private communication.

[6] `http://direct.xilinx.com/bvdocs/publications/ds022.pdf`.

[7] A. Zelenski et al., Proceedings of the 16th International Spin Physics Symposium, Trieste, Italy, 2004, p. 761;
A. Nass et al., Proceedings of the 16th International Spin Physics Symposium, Trieste, Italy, 2004, p. 776.

[8] H. Okada et al., Proceedings of the 16th International Spin Physics Symposium, Trieste, Italy, 2004, p. 507;
A. Bravar et al., Proceedings of the 16th International Spin Physics Symposium, Trieste, Italy, 2004, p. 700.

[9] N. Akchurin *et al*, Phys. Rev. **D48** (1993) 3026.